MHz, is taken to be 11.0 dB. This value is arrived at by noting that a rate 3/4 convolutionally encoded transmission link requires a theoretical E_b/N_0 of 7.0 dB for an information bit rate of 30 Mbps, and a decoded bit error rate of 10^{-8}. The theoretical CNR required then is 7 + 10 log (30/24), i.e., 8 dB. Adding 3 dB of implementation margin yields the 11 dB value. The 40 Mbps channel rate can be used for four excellent quality NTSC or two HDTV channels. This mode of transmitting data will be designated as "QPSK modulation", with 40 Mbps per carrier.

c) The third option is to use emerging data transmission systems that are being developed for 6 MHz cable TV channels. Each 6 MHz channel carries about 30 Mbps of data using 64 QAM modulation or its variant. It will be assumed that each 6 MHz can support four good quality NTSC channels. Such systems are being developed (by e.g., Jerrold and Scientific Atlanta) primarily for pay-per-view applications, but can also be used for four NTSC off-air broadcast channels, or one HDTV channel plus one NTSC channel. The CNR requirement will be assumed to be 30 dB in 6 MHz bandwidth. In such a system it is expected that the set-top box will deliver NTSC to the TV receiver on channel 3 or 4, similar to presently used set-top converters in cable systems. This mode of transmitting will be referred to as "64 QAM-cable modulation".

Table I-4.1 shows the CNR requirements for the candidate modulations. It should be pointed out that most satellite systems are designed to meet the criteria for a SNR of 50 dB. Cable systems, including modern installations that utilize fiber trunks have SNRs in the range of 43 to 47 dB. The Suite 12 system is designed for a fringe area reception of 55 dB which is studio quality.

TABLE I-4.1
CHARACTERISTICS OF MODULATION CANDIDATES

Modualtion candidate	Allocated Band-width	Carrier Band-width(B)	CNR(dB) required	CNR+B (dB-MHz)	Video channels per carrier	Video channels in GHz 1.0
FM	40 MHz	36 MHz	8.0	23.56	1	25
FM	27 MHz	24 MHz	8.0	21.80	1	37
FM	20 MHz	18 MHz	13.0	25.52	1	50
AM	6 MHz	6 MHz	42.0	49.78	1	166
Dig. HDTV	6 MHz	6 MHz	30.0	37.78	1	166
QPSK	27 MHz	24 MHz	11.0	24.80	4	148
64QAM	6 MHz	6 MHz	30.0	37.78	4	664

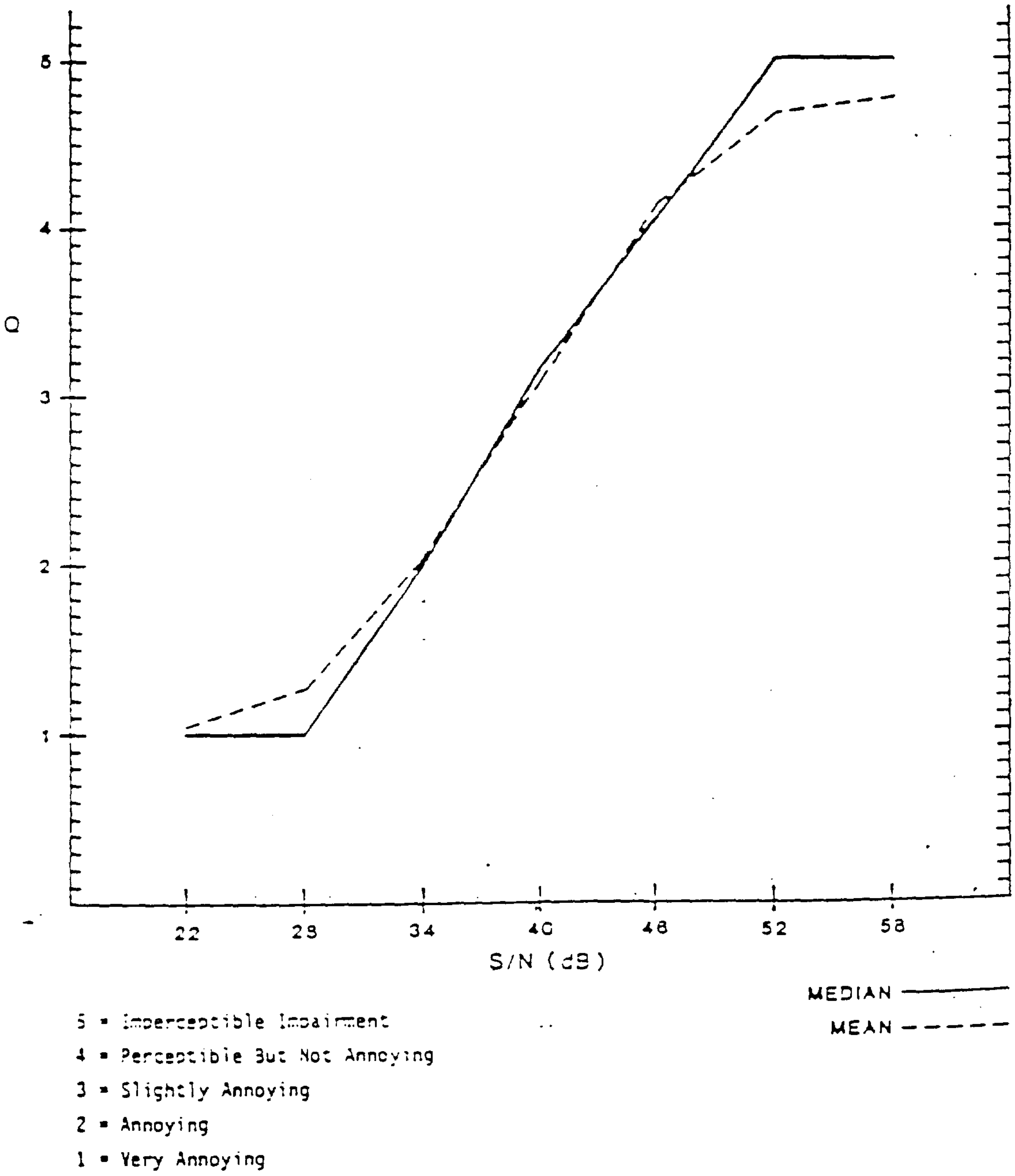


Figure I-4.1 NTSC signal to noise test.

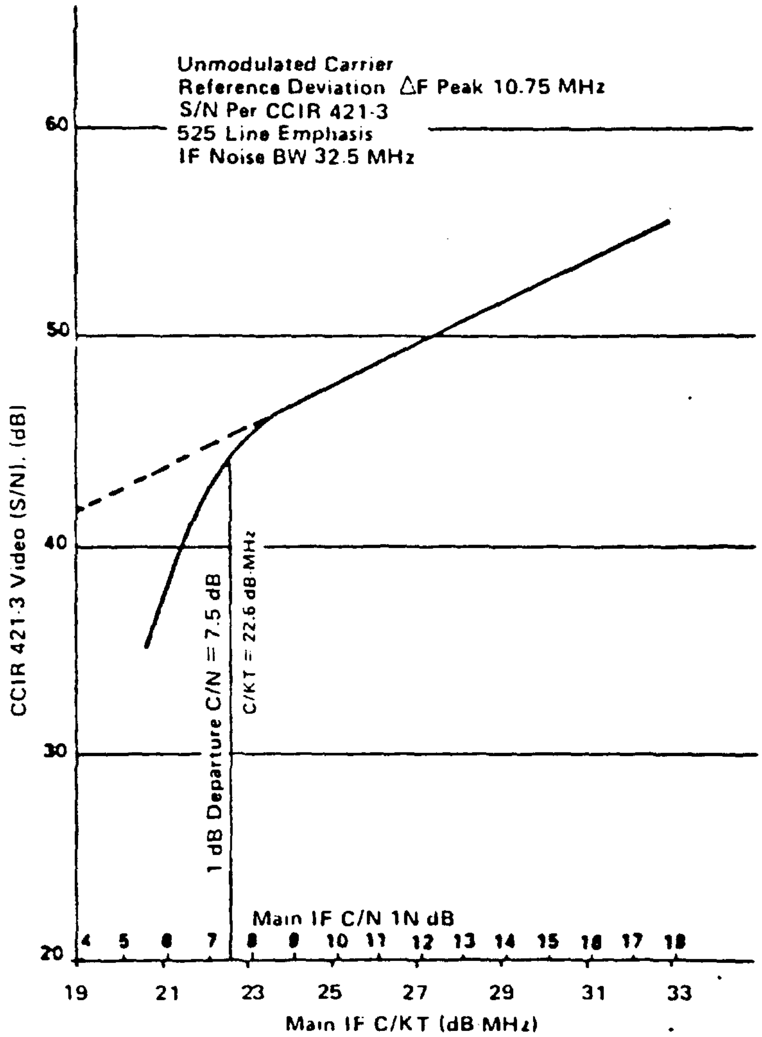


Figure I-4.2 Illustration of FM/video Receiver Threshold

Test Type: Random Noise, Miss TASO

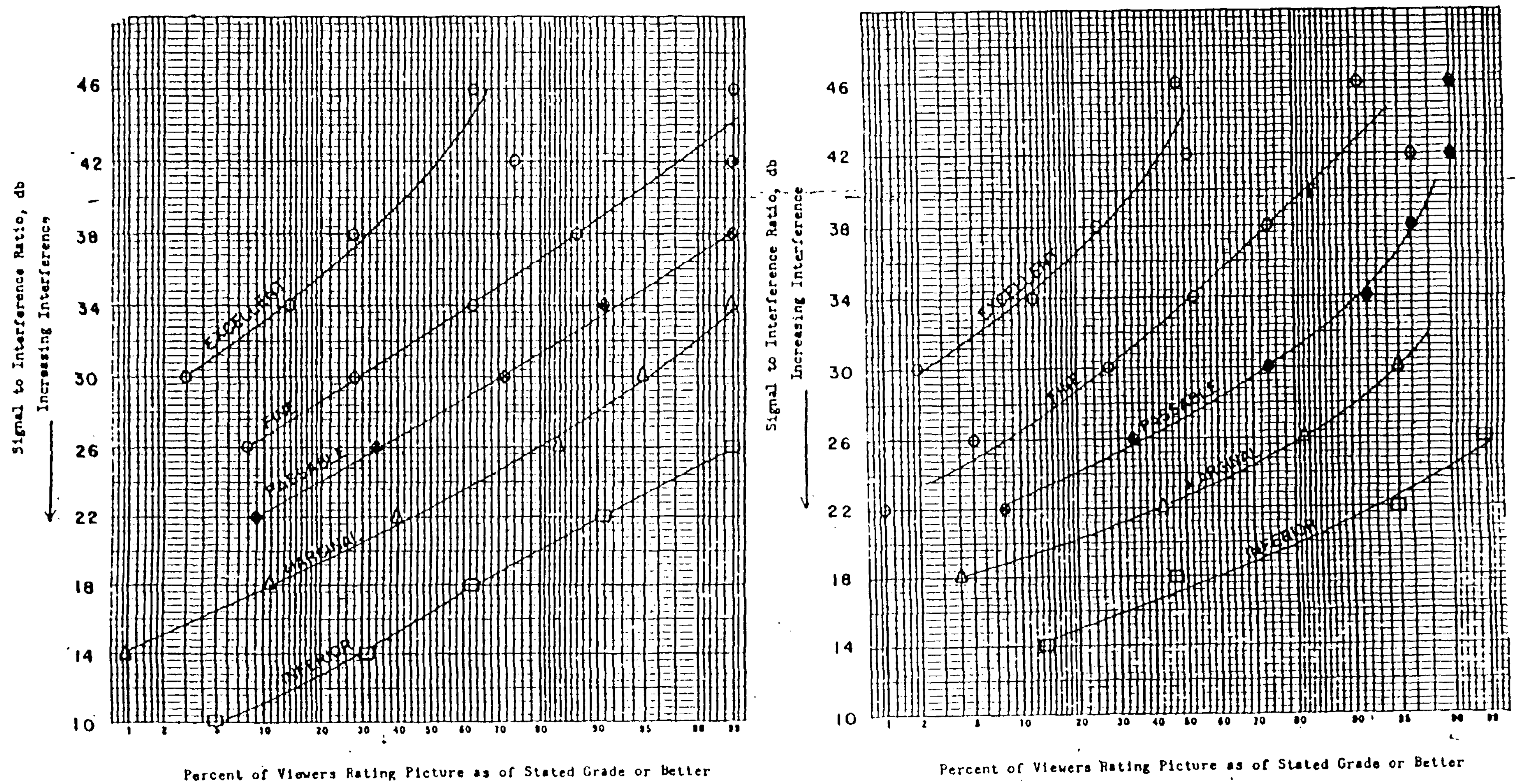
Tests Used: 9 (19M, 34J).

Subjects: 38 F and 38 M. Groups M2, M3, M5 and J3.

Test Type: Random Noise, Seven Scenes Pooled (not including Miss TA

Tests Used: 9C (53J), 9D (52J), 9F (49J), 9H (54J), 9K (48J), 9S (50J), and 9T (51J).

Subjects: 112 F. Group J5 (used seven times).



(a) (b)

Figure I-4.3 TASO data.

5. Link Analysis at Five Cities

The previous sections have provided the necessary technological background to perform link analyses which will provide the relevant information for comparing the system performance of the various modulation schemes.

A baseline receiving system is defined by assuming a receiver with 15 inch parabolic dish located at the outer fringe of a cell equivalent to a 7.5 in. diameter dish located at 0.75 of the cell diameter. The theoretical gain of the antenna at 55% efficiency, and at 28 GHz is 38 dB. The receiver noise figure (NF) will be assumed to be 6 dB, which corresponds to a noise temperature of 894.3°K. Then the power per video carrier at the antenna output under rain faded condition is

$$C = (\text{ERP/carrier}) - 36.58 - 20 \log 28000 - 20 \log D + 38 - 0.2603\, R^{1.038} (p/0.01)^{-0.41} D/(1 + 0.07151D), \text{dBW}$$

where R is the rain rate in mm/hr, and p% is the unavailability (in the range 0.01 to 0.1%). The noise power N for a bandwidth, B is

$$N = -228.6 + 10 \log B + 60 + 10 \log 894.3, \text{dBW}$$

The CNR is given by C-N, dB. Then we can show that

$$\text{ERP/carrier} = (\text{CNR} + 10 \log B) + 20 \log D - 51.56 + 0.2603\, R^{1.038} (p/0.01)^{-0.41} D/(1 + 0.07151D), \text{dBW}$$

Tables I-5.1 show the required values of ERP/carrier for New York and Los Angeles for 99.9% availability at path lengths from 2 to 6 miles. Among the candidates that carry one video channel per carrier, FM with 24 MHz bandwidth is the most attractive candidate, and AM (terrestrial standard NTSC) is the least attractive. It is seen that QPSK with 24 MHz bandwidth requires the least amount of ERP per channel, and also utilizes spectrum efficiently (6.75 MHz per video channel).

Table I-5.1 also shows power required per video channel from the transmitting system amplifier, for two assumed transmitter antenna gains: 6 dB for an omni directional antenna, and 18 dB for a directional antenna. It is also assumed that there is 1 dB signal power loss between the amplifier and the antenna. The superiority of FM transmission, relative to AM, is evident even if we compare the amplifier output power/carrier values of FM with 6 dB antenna (0.695W for 24 MHz FM) to AM with 18 dB antenna (27.5W).

Since 1 GHz of RF bandwidth (27.5 to 28.5 GHz) is available for service, we can compute the video channel capacity of this bandwidth for the seven modulation candidates. For AM to have a similar range to FM, the transmitted power must be 25 dB (or 316 times) greater after the appropriate backoff for proper IMR, which at the present time is far beyond the state-of-the-art. In addition, guard bands are required for AM to prevent intermodulation distortion from adjacent channels. The use of repeaters is not feasible in AM transmissions, due to the degradation of the signal to noise ratio for each repeater and the very high power level requirements. This is not the case for FM transmission. Although the channel capacity appears to be greater for AM than for FM, FM transmission allows the use of the same frequency for additional services within any given cell. This is due to the lower susceptibility of FM to an interfering signal at the same frequency. FM requires the desired signal to be only 15 dB greater than the undesired signal, while AM requires the undesired signal be 42 dB lower than the desired signal. Hence FM can be made very bandwidth efficient while requiring substantially less power per channel. The QPSK carrier capacity, with four channels per carrier, is comparable to the AM channel capacity. Unfortunately, this technology has not been proven for cellular wireless systems and is quite expensive. The highest capacity is obtained if all the carriers are 64 QAM-cable digital, with each carrier transmitting four video channels, but occupying only 6 MHz. However, as will be described later, there are serious technical problems with 6 MHz channelized RF transmission (at 28 GHz) which, to the best of our knowledge, require technology that does not exist now and will not exist in the foreseeable future. Also, the performance capability of 18 MHz FM is, technologically, well within the state-of-the-art, is low cost, and can provide a system which is initially competitive with cable. Unlike many existing cable systems, any innovative developments in technology or services developed for fiber or new cable systems can also be easily employed by the wireless cellular system. Figure I-5.1 shows the total ERP of all the carriers as a function of the number of video channels, for the seven candidate modulations.

Table I-5.2 compares the cell radius for various transmitter amplifier outputs on a per carrier basis. Note that for the same output power, FM has transmitting ranges which are three to almost ten times greater then the AM ranges. It should also be pointed out that a multiple channel transmitting TWTA requires operation in the linear range. For AM, this means that the total output power must be backed off 16 dB from the TWTA's saturated output power rating. In the FM case this backoff only has to be 7 dB. In order to achieve the same output power level the TWTA used for a multi-channel AM transmission requires nine dB or almost ten times the saturated output power required for FM transmissions. Realistically then, for the same transmitter and antenna, the FM system will have a range which is 10 to 30 times greater than the AM system.

Figure I-5.1 shows the total ERP of all the carriers as a function of the number of video channels. for the seven candidate modulations.

Based on these computations it is recommended that video distribution will be done using frequency modulation (FM) carriers spaced at 20 MHz. Each FM carrier is modulated with scrambled or unscrambled NTSC video signals. The FM bandwidth is 18 MHz. Forty-nine baseband video sources obtained from satellite and over the air channels, are frequency modulated. The TWTA has a single carrier saturation power rating of 100 W, and be operated at 7 dB output power backoff. Thus the TWTA output power per FM carrier is 0.4 W. Experimental data shows that at 7 dB backoff the intermodulation noise generated in any of the FM carrier frequency bands is low and is at a power level of -27.0 dB, relative to that of a single FM carrier power. The video FM link are provided with a carrier-to-total noise ratio (CNR) of 13.0 dB in the noise bandwidth of each of the FM carriers; the total noise includes the intermodulation noise and the receiver thermal noise. Note that a 7.5 inch reflector, which has a beamwidth of approximately 4.2°, can be used throughout 75% of the cell area without degrading the CNR. Results of link analysis at five cities are shown in Tables I-5.3 to I-5.7.

TABLE I-5.1
TRANSMITTER POWER REQUIREMENTS

Modulation Method	City	Distance (mi)	ERP Per Carrier (dBW)	Amplifier Output Required Per Channel (dBm) Antenna Gain 18 dB	6 dB
FM (36 MHz)	LA	2.0	-15.93	-2.93	9.07
FM (36 MHz)	LA	3.0	-9.92	3.08	15.08
FM (36 MHz)	LA	4.0	-5.21	7.79	19.79
FM (36 MHz)	LA	5.0	-1.29	11.71	23.71
FM (36 MHz)	LA	6.0	2.08	15.08	27.08
FM (36 MHz)	NY	2.0	-11.19	1.81	13.81
FM (36 MHz)	NY	3.0	-3.23	9.77	21.77
FM (36 MHz)	NY	4.0	3.22	16.22	28.22
FM (36 MHz)	NY	5.0	8.69	21.69	33.69
FM (36 MHz)	NY	6.0	13.45	26.45	38.45
FM (24 MHz)	LA	2.0	-17.69	-4.69	7.31
FM (24 MHz)	LA	3.0	-11.68	1.32	13.32
FM (24 MHz)	LA	4.0	-6.97	6.03	18.03
FM (24 MHz)	LA	5.0	-3.05	9.95	21.95
FM (24 MHz)	LA	6.0	.32	13.32	25.32
FM (24 MHz)	NY	2.0	-12.95	.05	12.05
FM (24 MHz)	NY	3.0	-4.99	8.01	20.01
FM (24 MHz)	NY	4.0	1.46	14.46	26.46
FM (24 MHz)	NY	5.0	6.93	19.93	31.93
FM (24 MHz)	NY	6.0	11.69	24.69	36.69
FM (18 MHz)	LA	2.0	-13.97	-.97	11.03
FM (18 MHz)	LA	3.0	-7.96	5.04	17.04
FM (18 MHz)	LA	4.0	-3.25	9.75	21.75
FM (18 MHz)	LA	5.0	.67	13.67	25.67
FM (18 MHz)	LA	6.0	4.04	17.04	29.04
FM (18 MHz)	NY	2.0	-9.23	3.77	15.77
FM (18 MHz)	NY	3.0	-1.27	11.73	23.73
FM (18 MHz)	NY	4.0	5.18	18.18	30.18
FM (18 MHz)	NY	5.0	10.65	23.65	35.65
FM (18 MHz)	NY	6.0	15.41	28.41	40.41
Terrestrial AM (6 MHz)	LA	2.0	10.29	23.29	35.29
Terrestrial AM (6 MHz)	LA	3.0	16.30	29.30	41.30
Terrestrial AM (6 MHz)	LA	4.0	21.01	34.01	46.01
Terrestrial AM (6 MHz)	LA	5.0	24.93	37.93	49.93
Terrestrial AM (6 MHz)	LA	6.0	28.30	41.30	53.30
Terrestrial AM (6 MHz)	NY	2.0	15.03	28.03	40.03
Terrestrial AM (6 MHz)	NY	3.0	22.99	35.99	47.99
Terrestrial AM (6 MHz)	NY	4.0	29.44	42.44	54.44
Terrestrial AM (6 MHz)	NY	5.0	34.91	47.91	59.91
Terrestrial AM (6 MHz)	NY	6.0	39.67	52.67	64.67
Digital HDTV (6 MHz)	LA	2.0	-1.71	11.29	23.29
Digital HDTV (6 MHz)	LA	3.0	4.30	17.30	29.30
Digital HDTV (6 MHz)	LA	4.0	9.01	22.01	34.01
Digital HDTV (6 MHz)	LA	5.0	12.93	25.93	37.93
Digital HDTV (6 MHz)	LA	6.0	16.30	29.30	41.30

TABLE I-5.1
TRANSMITTER POWER REQUIREMENTS (CONTINUED)

Modulation Method	City	Distance (mi)	ERP Per Carrier (dBW)	Amplifier Output Required Per Channe (dBm) Antenna Gain 18 dB	6 dB
Digital HDTV (6 MHz)	NY	2.0	3.03	16.03	28.03
Digital HDTV (6 MHz)	NY	3.0	10.99	23.99	35.99
Digital HDTV (6 MHz)	NY	4.0	17.44	30.44	42.44
Digital HDTV (6 MHz)	NY	5.0	22.91	35.91	47.91
Digital HDTV (6 MHz)	NY	6.0	27.67	40.67	52.67
64 QAM - Digital (6 MHz)	LA	2.0	-1.71	5.27	17.27
64 QAM - Digital (6 MHz)	LA	3.0	4.30	11.28	23.28
64 QAM - Digital (6 MHz)	LA	4.0	9.01	15.99	27.99
64 QAM - Digital (6 MHz)	LA	5.0	12.93	19.91	31.91
64 QAM - Digital (6 MHz)	LA	6.0	16.30	23.28	35.28
64 QAM - Digital (6 MHz)	NY	2.0	3.03	10.01	22.01
64 QAM - Digital (6 MHz)	NY	3.0	10.99	17.97	29.97
64 QAM - Digital (6 MHz)	NY	4.0	17.44	24.42	36.42
64 QAM - Digital (6 MHz)	NY	5.0	22.91	29.89	41.89
64 QAM - Digital (6 MHz)	NY	6.0	27.67	34.65	46.65
QPSK (24 MHz)	LA	2.0	-14.69	-7.71	4.29
QPSK (24 MHz)	LA	3.0	-8.68	-1.70	10.30
QPSK (24 MHz)	LA	4.0	-3.97	3.01	15.01
QPSK (24 MHz)	LA	5.0	-.05	6.93	18.93
QPSK (24 MHz)	LA	6.0	3.32	10.30	22.30
QPSK (24 MHz)	NY	2.0	-9.95	-2.97	9.03
QPSK (24 MHz)	NY	3.0	-1.99	4.99	16.99
QPSK (24 MHz)	NY	4.0	4.46	11.44	23.44
QPSK (24 MHz)	NY	5.0	9.93	16.91	28.91
QPSK (24 MHz)	NY	6.0	14.69	21.67	33.67

TABLE I-5.2

CELL RADIUS IN MILES FOR SELECTED VALUES OF TRANSMITTING AMPLIFIER POWER OUTPUT PER CARRIER.

Transmitter antenna gain: 10 dB

Rain availability: 99.9%

Receiver dish diameter: 15 inches

	New York				Los Angeles			
Power (dBm)	AM 6 MHz	FM 36 MHz	FM 24 MHz	FM 18 MHz	AM 6 MHz	FM 36 MHz	FM 24 MHz	FM 18 MHz
5	0.2	1.6	1.8	1.4	0.2	2.1	2.4	1.9
10	0.3	2.1	2.3	1.9	0.4	3.0	3.4	2.6
15	0.5	2.7	3.0	2.5	0.6	4.0	4.5	3.6
20	0.7	3.5	3.8	3.2	0.9	5.4	5.9	5.8

Table I-5.3

Suite 12 Video Distribution System Link Analysis

City: New York

		Subscriber Dish Diameter: 7.5 inch	Subscriber Dish Diameter: 15 inch
1.	Transmitting RF amplifier power per FM channel, dBW	-4.0	-4.0
2.	Transmitting antenna feed loss, dB	1.0	1.0
3.	Transmitting antenna gain, dBi	10.0	10.0
4.	Cell Radius, miles	3.0	3.9
	Cell Diameter, miles	6.0	7.8
5.	Free space loss (at 28 GHz), dB	135.1	137.3
6.	Receiver antenna gain, dBi	32.0	38.0
7.	Boltzmann's constant, dBW/K/Hz	-228.6	-228.6
8.	Bandwidth (18 MHz), dB-Hz	72.6	72.6
9.	Receiver noise temperature, dBK	29.5	29.5
10.	Carrier-to-Noise Ratio (CNR), dB	28.4	32.2
11.	Rain rate for 0.01% mm/hr	52.4	52.4
12.	Rain attenuation (99.9% availability), dB	15.0	18.6
13.	Rain faded CNR, dB	13.4	13.6
14.	Video Receiver Transfer Function, dB	29.0	29.0
15.	Clear weather Video SNR[1)], dB	53.6	54.8
16.	Rain faded SNR[1)], dB	42.2	42.4

[1)] Includes intermodulation noise produced by the transmitter TWTA.

Table I-5.4

Suite 12 Video Distribution System Link Analysis

City: Boston

		Subscriber Dish Diameter: 7.5 inch	Subscriber Dish Diameter: 15 inch
1.	Transmitting RF amplifier power per FM channel, dBW	-4.0	-4.0
2.	Transmitting antenna feed loss, dB	1.0	1.0
3.	Transmitting antenna gain, dBi	10.0	10.0
4.	Cell Radius, miles Cell Diameter, miles	3.1 6.2	4.1 8.2
5.	Free space loss (at 28 GHz), dB	135.3	137.8
6.	Receiver antenna gain, dBi	32.0	38.0
7.	Boltzmann's constant, dBW/K/Hz	-228.6	-228.6
8.	Bandwidth (18 MHz), dB-Hz	72.6	72.6
9.	Receiver noise temperature, dBK	29.5	29.5
10.	Carrier-to-Noise Ratio (CNR), dB	28.2	31.7
11.	Rain rate for 0.01% mm/hr	49.0	49.0
12.	Rain attenuation (99.9% availability), dB	14.4	18.0
13.	Rain faded CNR, dB	13.8	13.7
14.	Video Receiver Transfer Function, dB	29.0	29.0
15.	Clear weather Video SNR[1], dB	53.5	54.7
16.	Rain faded SNR[1], dB	42.6	42.5

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[1] Includes intermodulation noise produced by the transmitter TWTA.

Table I-5.5

Suite 12 Video Distribution System Link Analysis

City: Los Angeles

		Subscriber Dish Diameter: 7.5 inch	Subscriber Dish Diameter: 15 inch
1.	Transmitting RF amplifier power per FM channel, dBW	-4.0	-4.0
2.	Transmitting antenna feed loss, dB	1.0	1.0
3.	Transmitting antenna gain, dBi	10.0	10.0
4.	Cell Radius, miles Cell Diameter, miles	4.5 9.0	6.0 12.0
5.	Free space loss (at 28 GHz), dB	138.5	141.1
6.	Receiver antenna gain, dBi	32.0	38.0
7.	Boltzmann's constant, dBW/K/Hz	-228.6	-228.6
8.	Bandwidth (18 MHz), dB-Hz	72.6	72.6
9.	Receiver noise temperature, dBK	29.5	29.5
10.	Carrier-to-Noise Ratio (CNR), dB	25.0	28.4
11.	Rain rate for 0.01% mm/hr	30.0	30.0
12.	Rain attenuation (99.9% availability), dB	11.6	14.3
13.	Rain faded CNR, dB	13.6	14.1
14.	Video Receiver Transfer Function, dB	29.0	29.0
15.	Clear weather Video SNR[1)], dB	51.9	54.8
16.	Rain faded SNR[1)], dB	42.4	42.9

[1)] Includes intermodulation noise produced by the transmitter TWTA.

Table I-5..6

Suite 12 Video Distribution System Link Analysis

City: San Francisco

		Subscriber Dish Diameter: 7.5 inch	Subscriber Dish Diameter: 15 inch
1.	Transmitting RF amplifier power per FM channel, dBW	-4.0	-4.0
2.	Transmitting antenna feed loss, dB	1.0	1.0
3.	Transmitting antenna gain, dBi	10.0	10.0
4.	Cell Radius, miles Cell Diameter, miles	4.5 9.0	6.0 12.0
5.	Free space loss (at 28 GHz), dB	138.5	141.1
6.	Receiver antenna gain, dBi	32.0	38.0
7.	Boltzmann's constant, dBW/K/Hz	-228.6	-228.6
8.	Bandwidth (18 MHz), dB-Hz	72.6	72.6
9.	Receiver noise temperature, dBK	29.5	29.5
10.	Carrier-to-Noise Ratio (CNR), dB	25.0	28.4
11.	Rain rate for 0.01% mm/hr	30.0	30.0
12.	Rain attenuation (99.9% availability), dB	11.6	14.3
13.	Rain faded CNR, dB	13.6	14.1
14.	Video Receiver Transfer Function, dB	29.0	29.0
15.	Clear weather Video SNR[1)], dB	51.9	54.8
16.	Rain faded SNR[1)], dB	42.4	42.9

1) Includes intermodulation noise produced by the transmitter TWTA.

Table I-5..7

Suite 12 Video Distribution System Link Analysis

City: Chicago

		Subscriber Dish Diameter: 7.5 inch	Subscriber Dish Diameter: 15 inch
1.	Transmitting RF amplifier power per FM channel, dBW	-4.0	-4.0
2.	Transmitting antenna feed loss, dB	1.0	1.0
3.	Transmitting antenna gain, dBi	10.0	10.0
4.	Cell Radius, miles Cell Diameter, miles	3.0 6.0	3.9 7.8
5.	Free space loss (at 28 GHz), dB	135.1	137.3
6.	Receiver antenna gain, dBi	32.0	38.0
7.	Boltzmann's constant, dBW/K/Hz	-228.6	-228.6
8.	Bandwidth (18 MHz), dB-Hz	72.6	72.6
9.	Receiver noise temperature, dBK	29.5	29.5
10.	Carrier-to-Noise Ratio (CNR), dB	28.4	32.2
11.	Rain rate for 0.01% mm/hr	52.0	52.0
12.	Rain attenuation (99.9% availability), dB	14.9	18.4
13.	Rain faded CNR, dB	13.5	13.8
14.	Video Receiver Transfer Function, dB	29.0	29.0
15.	Clear weather Video SNR[1)], dB	53.6	54.8
16.	Rain faded SNR[1)], dB	42.3	42.6

[1)] Includes intermodulation noise produced by the transmitter TWTA.

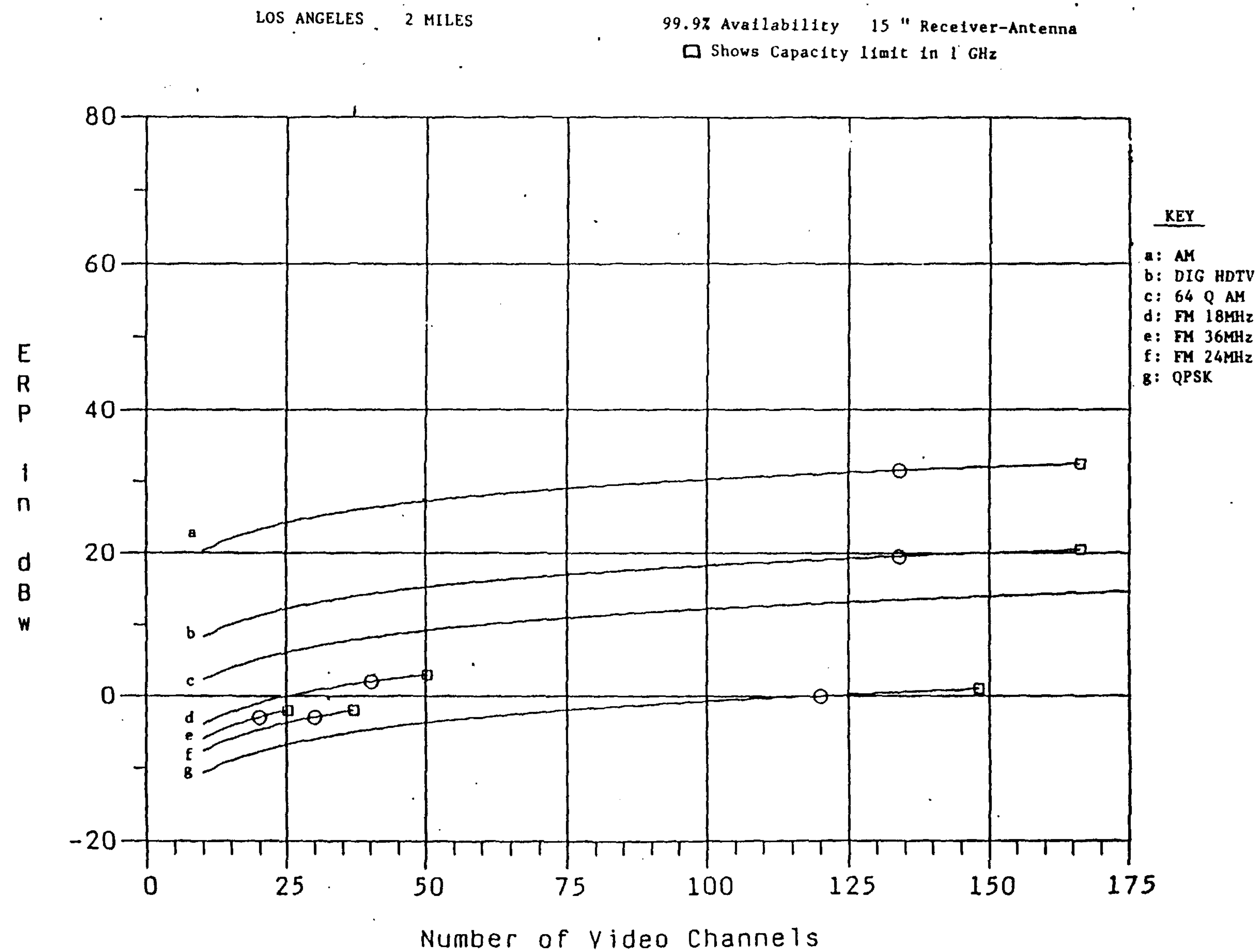

Figure I-5.1 ERP as a function of number of channels LA 2 miles.

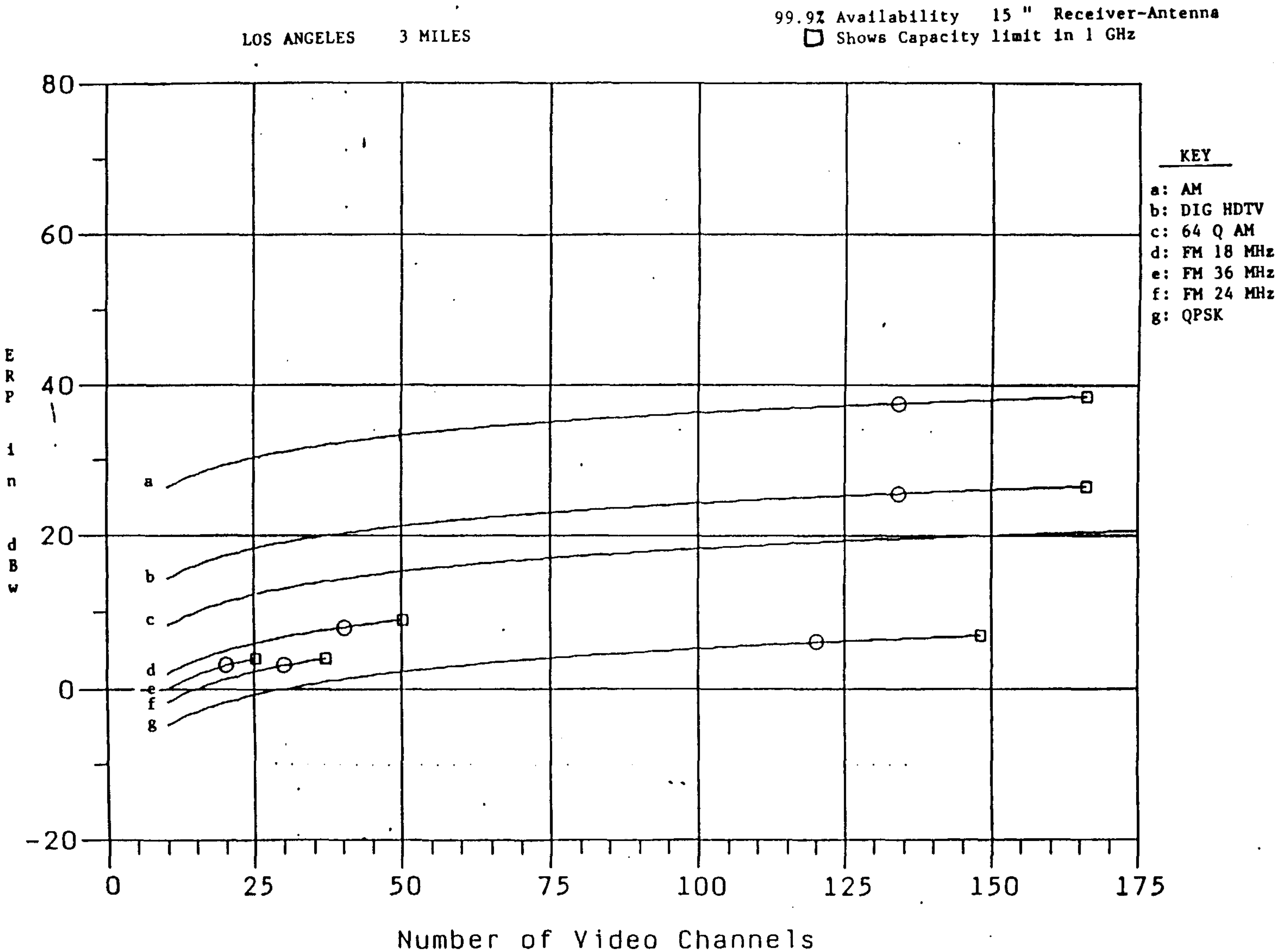

Figure I-5.1 ERP as a function of number of channels LA 3 miles.

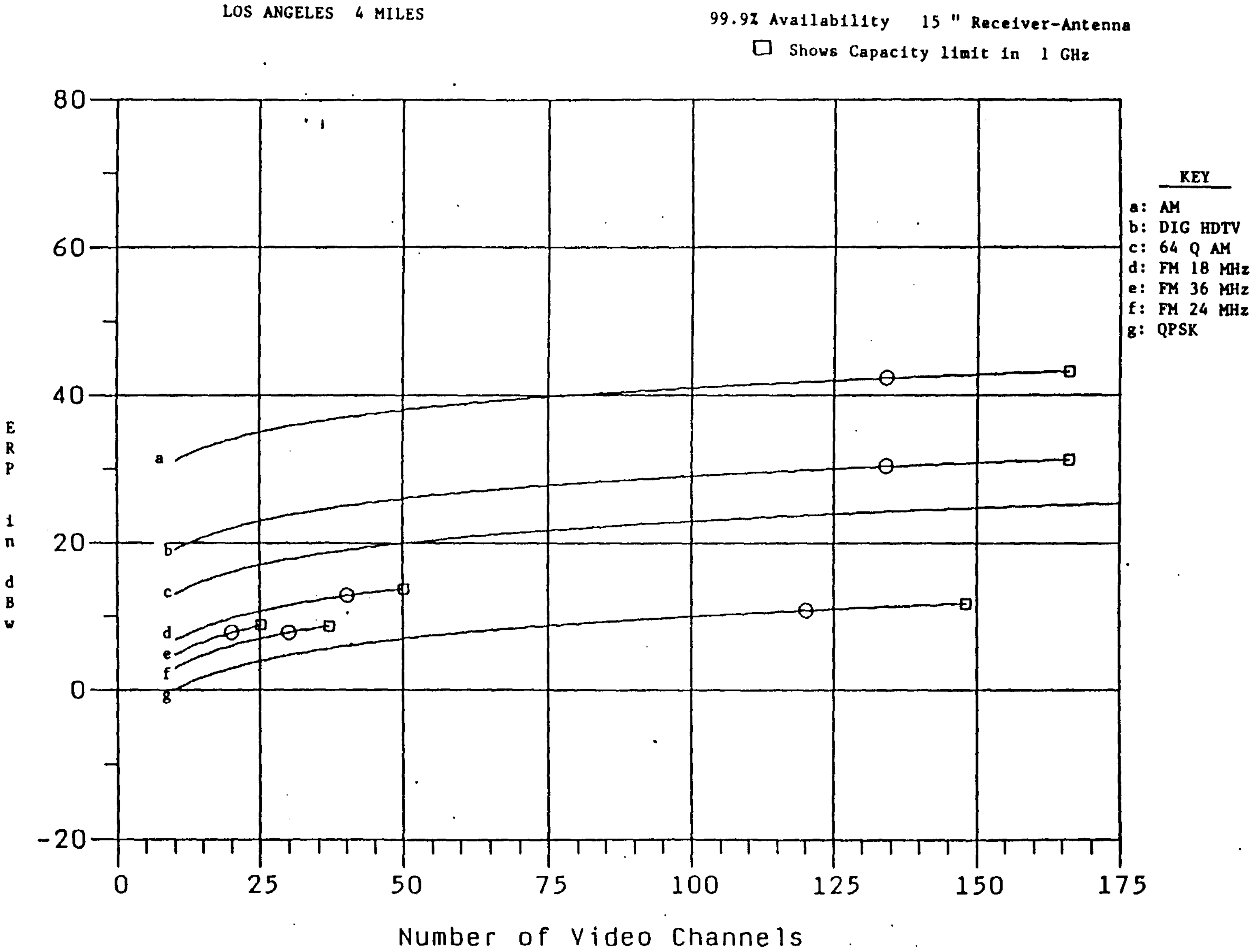

Figure I-5.1 ERP as a function of number of channels LA 4 miles.

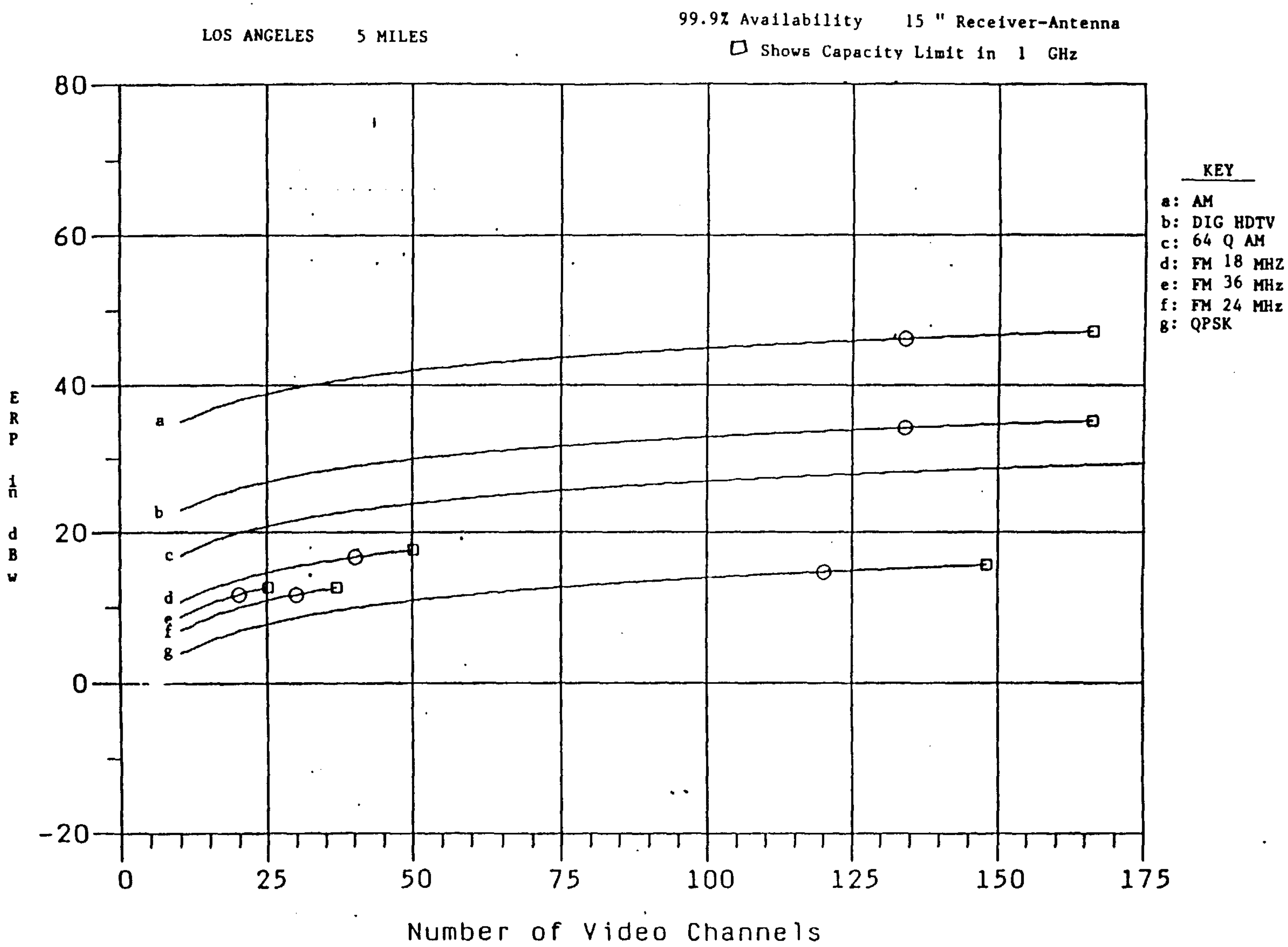

Figure I-5.1 ERP as a function of number of channels LA 5 miles.

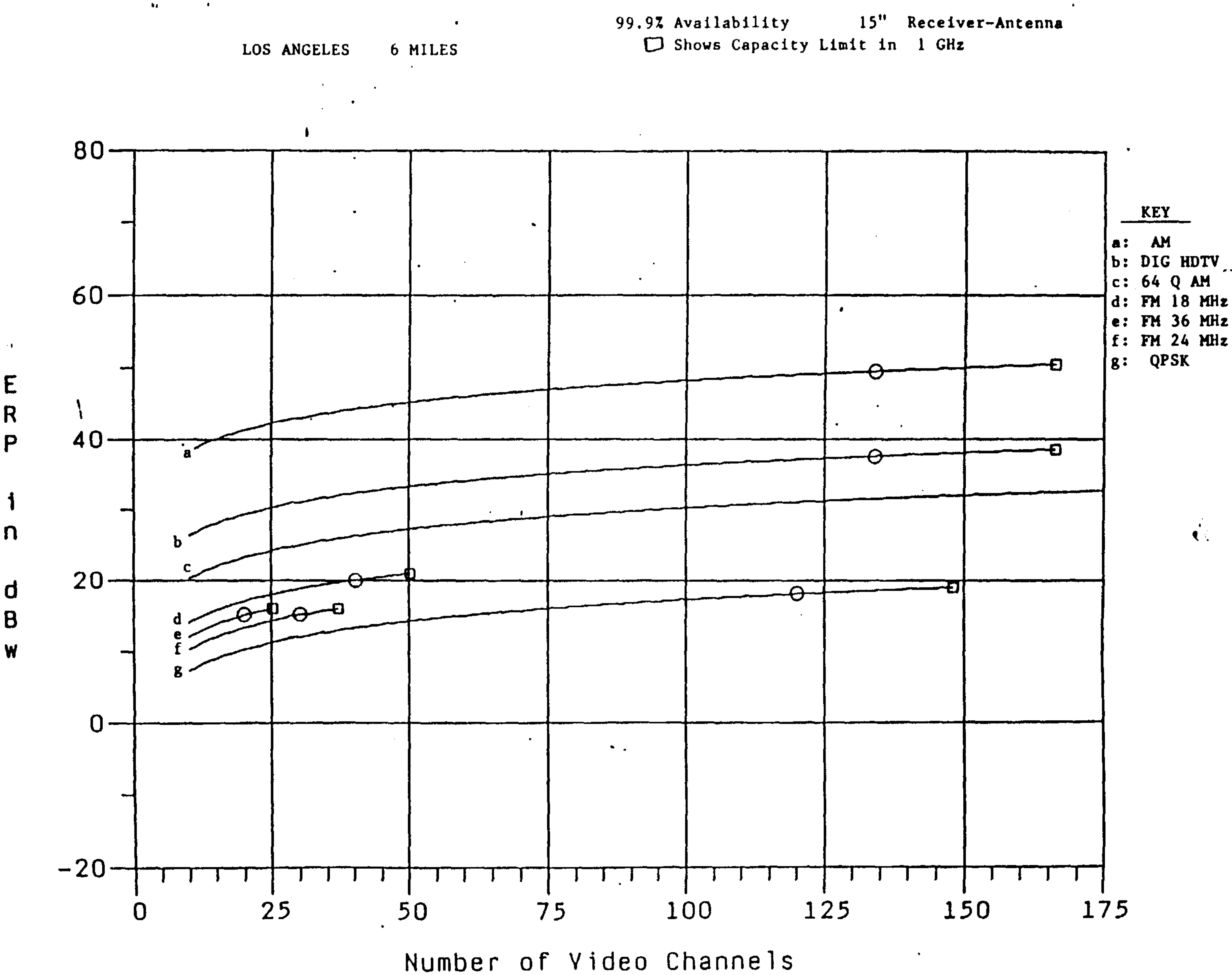

Figure I-5.1 ERP as a function of number of channels LA 6 miles.

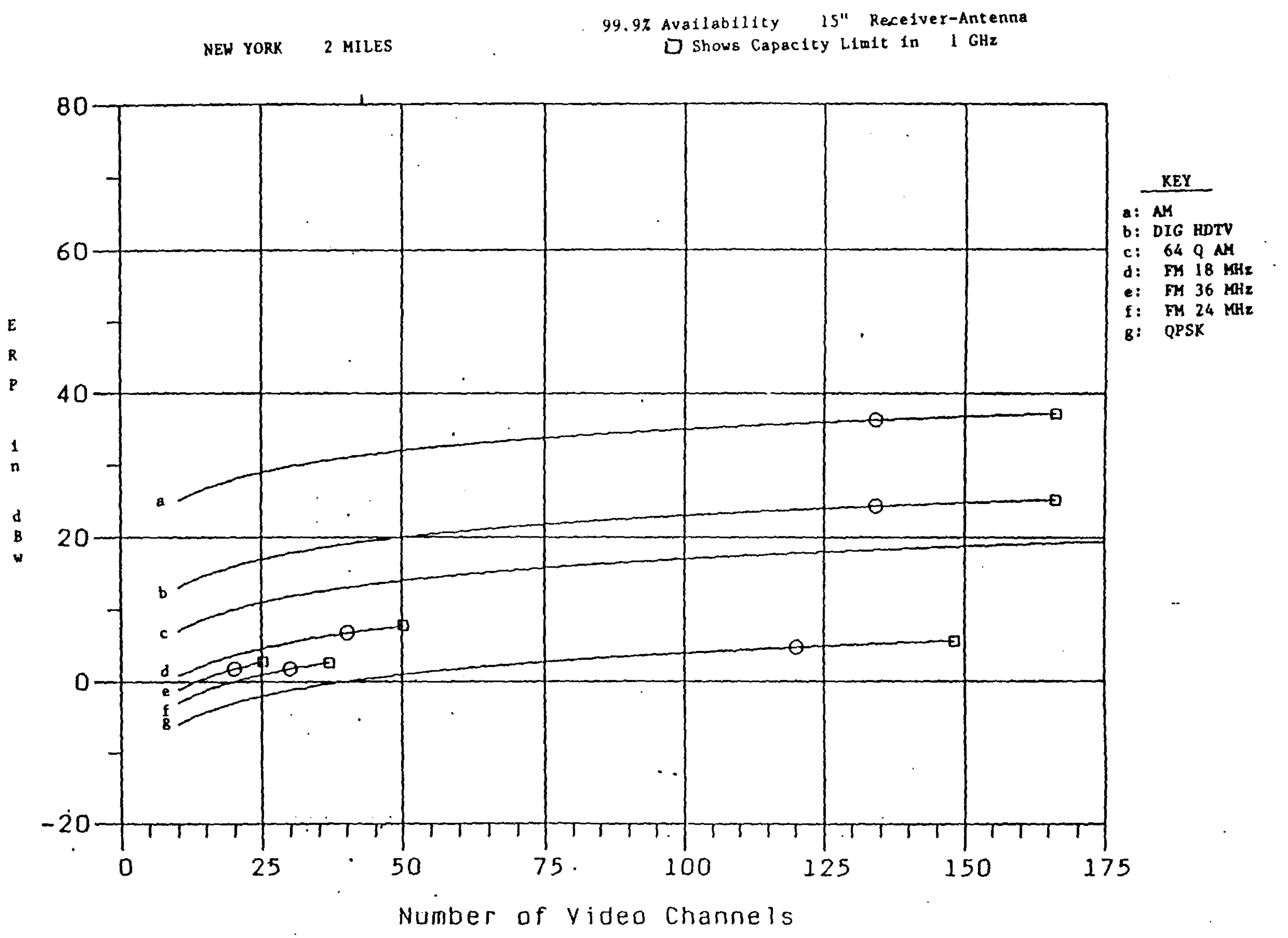

Figure I-5.1 ERP as a function of number of channels NY 2 miles.

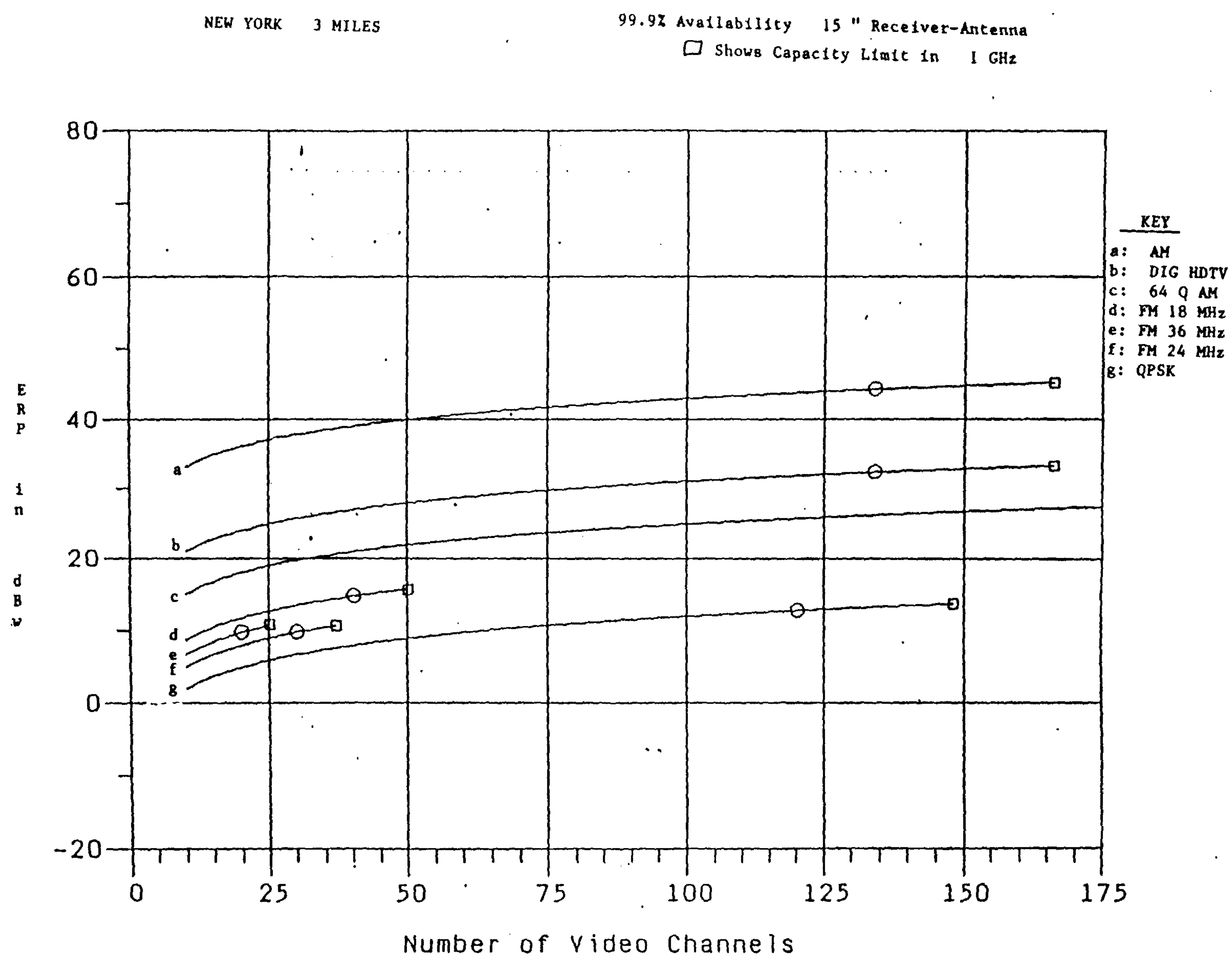

Figure I-5.1 ERP as a function of number of channels NY 3 miles.

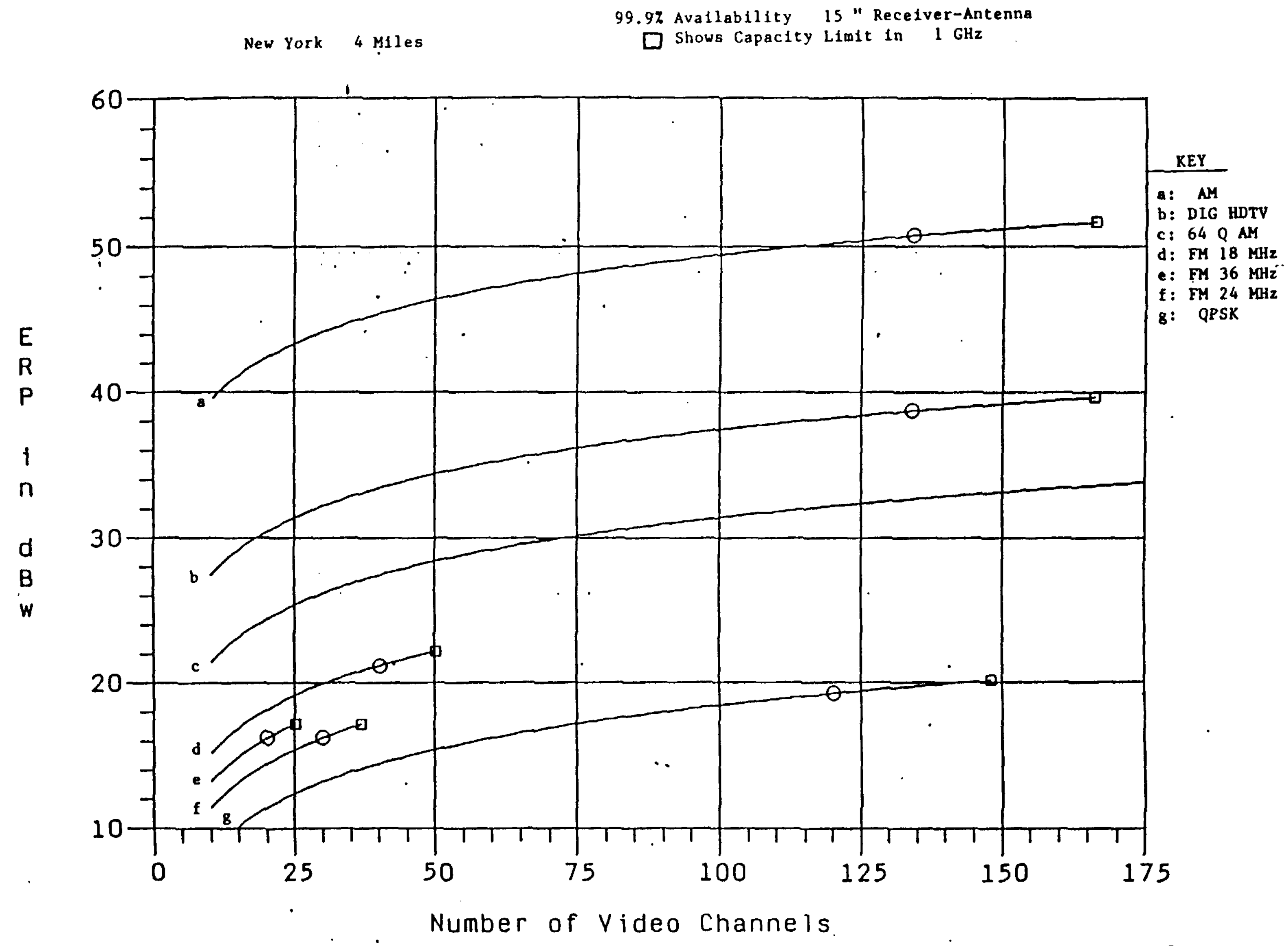

Figure I-5.1 ERP as a function of number of channels NY 4 miles.